INSTRUCTIONAL DESIGN AND ASSESSMENT

Using a Virtual Tablet Machine to Improve Student Understanding of the Complex Processes Involved in Tablet Manufacturing

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Objective. To develop and implement a virtual tablet machine simulation to aid distance students' understanding of the processes involved in tablet production.

Design. A tablet simulation was created enabling students to study the effects different parameters have on the properties of the tablet. Once results were generated, students interpreted and explained them on the basis of current theory.

Assessment. The simulation was evaluated using written questionnaires and focus group interviews. Students appreciated the exercise and considered it to be motivational. Students commented that they found the simulation, together with the online seminar and the writing of the report, was beneficial for their learning process.

Conclusion. According to students' perceptions, the use of the tablet simulation contributed to their understanding of the compaction process.

Keywords: virtual tablet machine, simulation, pharmacy education, expected learning outcomes

INTRODUCTION

One of the pedagogical problems frequently faced by distance students, particularly in online vocational program, is the lack of opportunity to train on practical elements of the course. This paper describes a project in which a virtual tablet machine was used to contribute to distance students' understanding of the processes involved in tablet production. The online Master of Science in Pharmacy Programme at Umeå University in Sweden includes the course Drug Formulation. Drug formulation deals with the design and manufacture of dosage forms (eg, tablets). An understanding of the compaction process is fundamental when developing tablets in the pharmaceutical industry, and knowledge in this area is essential to pharmacy students. Tablets consist of the active substance (or substances) and excipients. Excipients are added in order to facilitate the compaction into tablets and to improve and control the properties of the tablets. During the manufacture of tablets, suitable excipients and compaction parameters must be chosen, such as compaction pressure and compaction speed, to obtain tablets with desired properties regarding, for example, tensile strength and disintegration time.

Simulations can be successfully used in education to illustrate complex relationships during a limited time frame, and they are also ideal in distance education as they do not require access to expensive laboratory facilities and can be carried out by the student at any time and place. Compaction of tablets is an example of such complex relationships where a simulation could be beneficial to the students to aid their understanding of the process. The use of simulation training in health care education is spreading rapidly.¹⁻⁴ Previous studies demonstrated positive effects on skill or proficiency development.⁵⁻⁹ In pharmacy education, simulations are used in the following areas: pharmacotherapeutics, communication and patient care and safety, and the simulations used are often high-fidelity mannequins and virtual patients.^{4,8,9} Vyas et al investigated the use of simulation-based teaching methodologies in the United States and concluded that although simulations are used to some extent in the pharmacy curricula the role of simulations could be further expanded.⁸ Further, Cannon-Diehl showed that students had higher expectations concerning course content, and virtual simulations that were able to engage participants were likely to appeal to students.¹⁰ Several studies identified factors affecting the capacity of simulations to improve learning outcomes.^{1,5} McGaghie et al found that: additional feedback, on top of the experience itself, enhanced students' learning experience; repetitive practice

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involving simulations was associated with improved learner outcomes; and simulations needed to be integrated with other activities within a course such as laboratory work to be successful in facilitating student learning.⁵ Simulations have also been used in research in the area of drug formulation to describe and predict different behavior during compaction of tablets.^{11,12} For example, Yliruusi et al used a 3D simulation to simulate bond formation during compaction.¹¹

In the present course, a wiki was used to create a laboratory report based on the results from the simulation exercise. Wikis have previously been used in education and have been shown to enhance the learning process and facilitate cooperation and interaction between distance students.^{13,14} The aim of the project was to investigate if a virtual tablet machine could be used to aid distance students' understanding of the processes involved in tablet production and to document and evaluate the development and use of the tablet simulation in pharmacy education.

DESIGN

Drug Formulation is a required course in the fourth year of the online Master of Science in Pharmacy Programme at Umeå University in Sweden. One of the expected learning outcomes of the course is to understand and explain relationships between composition, compaction process, and properties of tablets (Table 1). To

facilitate this, a tablet simulation (ie, the virtual tablet machine) was created to illustrate these complex relationships and to investigate if such a simulation could be used to improve student learning. The simulation was included as a compulsory part of the course. At the end of the course, students take a written examination covering the course learning outcomes. The course learning outcomes are also assessed with laboratory work, laboratory reports, and a literature assignment (Table 1). The simulation was developed in parallel with development of the course curriculum as well as the development of the whole Master of Science in Pharmacy Programme.

An online tablet simulation was created enabling the students to choose different compositions, compaction pressures, and compaction speeds to observe the effect these parameters have on the properties of the tablet produced. One of the major challenges of this project was to combine the expertise of the educational technologists with the expertise of the subject specialist/teacher, enabling the transference of ideas into practical applications. The development began with the teacher explaining the theory behind the mechanics of tablet compaction to the educational technology team.

To simplify the process, the components of tablet compaction were sketched and mapped out omitting all details. The point was to capture the core values of tablet compaction and to understand the principles of the process involved in the production of tablets. During the

Table 1. Expected Learning Outcomes of the Course and Student Assessment

Expected Learning Outcome	Student Assessment
Describe and apply methods used for the characterization of solid state structure, size, shape, surface, and pore structure of particles	Written examination, laboratory work
Describe methods for the characterization of mechanical and compaction properties of powders as well as the mechanisms behind the compaction of powders	Written examination, tablet simulation
Explain the relationships between the physical properties of particles and the properties of tablets	Written examination
Apply methods used in the granulation of powders, manufacture of tablets, and characterization of tablets	Laboratory work
Understand and explain the relationships between composition, compaction process, and properties of tablets	Written examination, tablet simulation
Design stable and optimized formulation for delivery of proteins	Written examination
Design systems for the controlled and optimized delivery of drugs	Written examination
Describe and understand the concepts of quality assurance in the development and manufacture of dosage forms	Written examination
Describe the principals for the formulation, manufacture, control, and documentation of nonsterile and sterile extemporaneous drugs	Written examination
Critically review scientific articles in the area of pharmaceuticals and develop the ability to write scientifically and communicate orally in English	Literature assignment
Account for experimentally obtained results, both in writing and orally, using relevant manufacturing protocols and documentation	Tablet simulation (wiki), laboratory work

documentation process using video cameras and photographs, it became apparent that an accurate representation of a tablet machine was not helpful to the student in the process of understanding the core concepts of the compaction process. A realistic representation of an actual tablet machine would have lacked the indications of internal mechanisms that are necessary components in the design and development of a pedagogical simulation. To design and understand the steps of compaction, flowcharts and paper sketches were used since they provide a simple and nontechnical perspective when prototyping a virtual simulation model.

The simulation consisted of two main activities: the first activity contained an introductory laboratory component and was followed by an analytical component to give the students the opportunity to review and reflect on the generated data. We made some decisions concerning the laboratory activity to delineate the range of possible outcomes. A real physical tablet machine allows for an unlimited number of input variables; however, this would generate too much data and would require a considerable amount of programming. The boundaries set in this case were the number of compositions and the number of selectable active input values. By means of these delineations, the analytical activity also became more manageable in terms of the amount of data for the student to interpret.

The graphic user interface was then created to illustrate and enhance the steps made in creating a tablet (Figure 1). We built an intuitive workflow corresponding to the actual laboratory experience. The challenge was to guide the student through the virtual laboratory activity without disabling too many selectable options. This was achieved by creating an informative introductory text and by delivering a continual instructional dialogue.

The following tools were used when creating the simulation: graphic design – Photoshop, user interface – Adobe Flash, and programming – Action script 3.0 (all Adobe Systems Inc., San Jose, CA).

It was considered important to integrate the virtual tablet machine into an authentic context to bring it closer to reality and improve learning outcomes.⁴ When developing new drug formulations in the pharmaceutical industry, much time is devoted to finding the right formulation for that particular drug substance. Therefore, a series of experiments are set up where different excipients and different amounts of excipients are tested. Furthermore, parameters such as compaction pressure and compaction speed are varied during the experiments. The assignment was to make a series of experiments to choose a suitable formulation for a new drug substance. Instructions on how to perform the assignment were supplied in written form and as an audio-visual recording.

After students performed the online simulation, results were displayed in the form of graphs, which could then be interpreted and explained by the students on the basis of current theory. The results of the simulation were first discussed during an online seminar and thereafter the students worked together (in groups of four to five) writing a report using a wiki. A wiki is an online tool that can be used for virtual collaboration.^{10,11} One wiki was created for each group of students, and only the group and the teacher had access to it. Each student in the group edited the wiki, which enabled students to reflect on and review each other's contribution to it. According to the instructions, each student was to make at certain number of contributions to the wiki to involve the whole group in writing the report. Students also received additional feedback from the teacher. The report created using the wiki was then graded by the teacher. During the course, students

Figure 1. Screenshot displaying the virtual laboratory part of the simulation.

also manufactured real tablets; the tablet simulation therefore also serves as preparation for these practical experiments.

After the simulation had been completed, it was evaluated by students using written questionnaires and focus group interviews. No ethical committee approval was sought prior to beginning this research, as it is not obligatory by Swedish law for this type of study. Simulation-based learning has previously been evaluated using surveys to study students' perceptions and satisfaction with the simulation learning experience.^{4,15}

The students completed one part of the written questionnaire shortly after performing the simulation and the other part was completed after the course ended (Tables 2 and 3). The focus group interviews were performed after the simulation was completed, in connection with practical laboratory work by an educational developer from the university's Centre for Educational Development. Students were interviewed in groups of 6-8, and the interviews were recorded digitally and transcribed verbatim by the interviewer. The transcripts were analyzed thematically to elicit the main topics and themes discussed by students. During the focus group interviews, students were asked open-ended questions regarding their thoughts about the simulation: if they considered it to be of value for their learning and if the simulation was beneficial in helping them understand the theory of tablet compaction. Furthermore, students were asked questions about the most appropriate time during the course to complete the simulation and were also given the possibility to suggest improvements to the simulation (Table 4).

In the first section of the questionnaire, students were asked questions about the instructions, the operation and use of the virtual tablet machine, their expectations, and their understanding of the theoretical background (Tables 2 and 3). The second section contained questions regarding the wiki and if the simulation contributed to the students being better prepared for the laboratory experiments (Tables 2 and 3). In the questionnaire, a 6-point scale was used (1=no, not at all and 6=yes, absolutely). Points 2-5 were not further defined in the questionnaire. The students were also given the opportunity to comment on each of the questions.

EVALUATION AND ASSESSMENT

The tablet simulation was used as part of the laboratory experiments in the Drug Formulation course. The course was given on four different occasions (2011-2014), and 62 students performed the simulation. The focus group interviews were performed by 22 of 23 students taking the course during the years 2011 and 2012. Thirty-six of 62 students completed the written questionnaires

from 2011-2014, and this was considered a valid response rate. Results from the focus group interviews are summarized in Table 4. The concurrency among the students during the focus group interviews was very high.

The simulation took about one hour (60 ± 57 minutes) to complete, and most students performed the simulation individually (Table 3). The time to complete the simulation varied among students, ranging from 10 minutes to five hours. Generally, students performed the simulation more than once (Table 3). Regarding the question about the students' expectations, several students commented that they did not have any expectations. Five students were concerned it would be difficult to perform the simulation but concluded afterwards that this had not been the case. Other comments regarding expectations were that the simulation would be fun and interesting to use, as well as interesting to learn more about compaction of tablets and the effect of excipients (Table 3). Based on results from the evaluation, students found the instructions sufficient to complete the exercise. Seventy-one percent of the students responded 5 or 6 on the scale, where 6 corresponds to yes absolutely (Table 2).

As this was an online program, all students were accustomed to working with computers, and students also had some previous experience working with simulations (Table 2). In a course in analytical chemistry prior to the course in drug formulation, students used a similar simulation dealing with chromatography. Seventy-four percent of students responded 5 or 6 on the scale, indicating that a majority of the students considered that the tablet simulation had contributed to their understanding of the compaction process (Table 2). This was supported by the focus group interviews (Table 4).

Some operational problems were reported from the first version in 2011 such as difficulties in changing the compaction pressure and speed. The presentation of results as graphs was considered somewhat unclear. This was improved upon in the second version of the virtual tablet machine in 2012. However, some operational problems were still reported by the third and fourth group using the simulation; the overall opinion among students, however, was that the simulation was easy to use.

Students were also asked if using the wiki contributed to their learning (Table 2). Generally, students found the wiki useful for online collaboration to complete the laboratory report. However, some of the students thought that the wiki could be easier to work with and that it didn't contribute to their learning. During the focus group interviews, several students commented that the simulation together with the online seminar afterward and the written report was beneficial for their learning process (Table 4). This was also commented on in the questionnaire (Table 3).

Table 2. Questions Asked in the Written Questionnaire After the Tablet Simulation and Course Were Completed

Questions (no. of student responses)	Mean	% of Students					
		1 ^a	2	3	4	5	6
First section							
Do you have any previous experience of performing computer simulations? (n=36)	4.3	16.7	2.8	8.3	16.7	16.7	38.9
Were the instructions for the tablet simulation clear? (n=35)	5.0	0	2.9	8.6	17.1	25.7	45.7
Have the expectations you had before you started the tablet simulation exercise been met? (n=33)	4.3	3.0	12.1	9.1	27.2	24.2	24.2
Has working with the tablet simulation increased your understanding of the compaction process and the parameters that affect the finished tablet's properties? (n=35)	4.9	5.7	2.9	5.7	11.4	31.4	42.9
Has working with the tablet simulation increased your motivation to learn the theory of compaction? (n=36)	4.7	2.8	8.3	8.3	13.9	27.8	38.9
Did working with the tablet simulation increase your motivation prior to the practical laboratory sessions? (n=36)	4.4	5.6	5.6	16.7	19.4	25.0	27.8
Second section							
Did you experience the presentation of the tablet simulation using a wiki as supportive for your learning? (n=29)	4.2	10.3	3.4	17.2	24.1	13.8	31.0
Do you feel that the online tablet simulation contributed to making you better prepared for the practical tablet production activities? (n=27)	4.4	3.7	3.7	14.8	22.2	37.0	18.5

^aScale: 1=no, not at all and 6=yes, absolutely

A majority of students thought that working with the tablet simulation increased their motivation to learn compaction theory (81%) and their motivation prior to the practical laboratory sessions (72%) (Table 2). Regarding whether the simulation contributed to students being better prepared for the laboratory experiments, a majority of students (78%) said that it did (Table 2). However, some students commented that the simulation enhanced their theoretical knowledge but not their practical skills. Students reported that they preferred performing the simulation prior to the practical laboratory experiments (Table 5).

DISCUSSION

The development of a virtual tablet machine was a challenge, both technically and pedagogically. From the teacher's perspective, the goal was to develop a simulation that would be easy to use and help the students better understand the compaction process and the factors affecting the production of a final tablet. The focus of the simulation was on generating results that students in the next step could interpret and discuss. The focus was not to develop a simulation mimicking the actual tablet manufacturing process. The aim of the virtual tablet machine was to contribute to the student's understanding of the compaction process and, based on the results of the evaluation, students perceived that their understanding of the compaction process increased. Previous studies

showed a correlation between student perception and learning outcomes,^{16,17} which indicates that, while based on student perception data, students' understanding of the compaction process improved. However, this should be verified by evaluating data from relevant examination questions. Unfortunately, this data was not gathered; the results are, therefore, based on the written questionnaire and the focus group interviews.

By using a tablet simulation, it was possible for the students to obtain information about the factors influencing the compaction process and also to acquire this information during a limited time frame compared with the same information being obtained during practical experiments. The simulation took about one hour to complete, with a rather large variation (Table 2). This variation could be a result of some students experiencing technical problems and students including time to interpret the results in the estimation. Students considered the simulation to be good theoretical preparation for the practical experiments and, therefore, they preferred performing the simulation prior to the practical experiments. The combination of performing the tablet simulation and practical laboratory experiments most likely contributed to students' understanding of the compaction process. However, it is reasonable to assume that the tablet simulation alone would not have achieved the same understanding of the complex relationships affecting the compaction of tablets. It would be interesting to compare the results on written

Table 3. Questions Asked in the Written Questionnaire After the Tablet Simulation and Course Were Completed (no. of student responses)

Open-ended Questions (first section)		
How many times did you use the tablet simulation? (n=30)	2.6 (1.7) times ^a	
How long do you estimate that the exercise took in total? (n=33)	60 (57) minutes ^a	
Did you work individually with the tablet simulation or did you work in a group? (n=34)	Individually 73.5%	Group 26.5%
What expectations did you have before you started the tablet simulation exercise? (n=26)	None (10) To learn more about the correlation between process parameters and tablet properties (4) That it would be difficult (6) Fun and easy (3) High (1) More information about excipients, more explanations (2)	
Was there something that you felt was particularly difficult about the exercise? (n=26)	No (11) Technical problems (9) Understanding/interpreting the results (2) Time consuming (1) Finding limits for e.g. disintegration time (1) Understanding the instructions (2)	
Was there something that you felt was particularly good about the exercise? (n=27)	No (2) Fun exercise (2) Easy to use (6) Quick exercise (6) Understanding and learning more about the compaction process (12) The discussion of results with the teacher afterwards (4) Writing the report (1)	

^aMean (SD)

examinations of students who performed the experiments using the virtual tablet machine with students performing only traditional practical experiments to more objectively study the effect on student understanding of the compaction process. However, such a comparison was not possible as the course and the simulation were developed at the same time. The Drug Formulation course has thus not been given without the tablet simulation. Furthermore, it is not desirable to exclude some students from the group as the goal is to give the whole group the same opportunity to work with the simulation.

Students commented that the simulation together with the online seminar afterwards and the written report was beneficial for their learning process. This aligns with earlier research, which states that by giving the students the possibility to reflect and discuss the results of the simulation, the learning process is further facilitated.⁵ Although most of the students performed the simulation individually, the online seminar and the written report made possible collaboration between students and also between the students and teacher, which further facilitated

the learning process. Also, from a teacher's perspective, using the simulation made explanation of the compaction process and the complex relationships easier compared with previous experiences of teaching students without the aid of the simulation.

By using a wiki, each student's contribution can be seen and together students can create a written laboratory report. Generally, the students found the wiki useful and supportive of their learning. This supports previous results using wikis in education.^{14,18} One reason students found the wiki useful may have been that this was an online course and thus the wiki facilitated collaboration among students. The wiki helped and stimulated students to work with the report in a more integrated way and not divide the report among them.

In the questionnaire used to evaluate the tablet simulation, a 6-graded scale was chosen to make students choose if, overall, they felt positively or negatively about the statement. However, points 2-5 were not further defined in the scale. Therefore, the responses from

Table 4. Questions Asked During the Focus Group Interviews and Summary of the Results

Q1	You have carried out a virtual tablet simulation online – have you all done the computer simulation? How did you experience using the simulation?	Easy to use but some technical problems with adjusting speed and pressure. Also some problems with data not being displayed in the graph.
Q2	Do you feel that it is of value, feels meaningful to do the computer simulation online?	Yes
Q3	Was it advantageous to do the simulation before you did the practical activity in the laboratory or do you think that it would have been better to do it afterwards?	Before the practical experiments is better. It was advantageous since you then know more about the parameters affecting tablet properties
Q4	Do you think it has helped you to understand the theory behind the compaction process?	Yes, together with the discussion afterwards. The seminar and discussion afterwards were very useful. The seminar was very good.
Q5	Did doing the simulation, working with the presentation of results in the Wiki and then having a seminar help you to understand the tableting process? Do you think it was the simulation activity that helped or would you have understood just as easily without it?	The simulation gives an overview of the process and that aids the understanding. The simulation is necessary for the further discussions. The graphs are more important than the simulation itself.
Q6	Could the simulation exercise be improved in any way? Do you have any suggestions?	To be able to choose more compositions. Improve the way speed and pressure is changed. To be able to print the graphs.

the students may have varied depending on each student's own perception of what points 2-5 meant in relation to points 1 and 6.

In the simulation, it was not possible for students to choose the compositions freely; they could only choose from four fixed compositions. Comments given during the focus group interviews suggested that the ability to choose more compositions was desirable. For this to be possible, the database will have to be expanded considerably. Simulations are used in research within the area of drug formulation to describe and predict different behavior during tablet compaction. However, the tablet simulation presented in this paper was developed using fixed data obtained by practical experiments using a tablet machine. In that sense, it differed from some simulations described in literature in the area of drug formulation.

A possible future development of the project could be to implement the virtual tablet machine in a virtual environment. This could have pedagogical benefits regarding interaction among students. A virtual laboratory environment was previously shown to be a good complement to practical laboratory exercises.¹⁹

SUMMARY

The use of the tablet simulation, in combination with practical experiments and assignments, contributed to students' understanding of the compaction process according to the students' perceptions. The development of the tablet simulation provided a suitable technological solution to a pedagogical problem in an

online Pharmacy Program course. The simulation was useful when illustrating the complex relationship between the parameters that influence the properties of pharmaceutical tablets.

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